Modeling Sedimentary Deposits on the Continental Margin

Donald J. P. Swift
Department of Oceanography, Old Dominion University, Norfolk, VA, 23908
Ph. (757) 683-4937; Fax (757) 683-5303; dswift@odu.edu

Alan W. Niedoroda
URS Corp, 3676 Hartsfield Rd, Tallahassee, Florida U.S.A.
Ph. (850) 574-3197; Fax (850) 576-3676; Alan_Niedoroda@urscorp.com

Christopher W. Reed
URS Corp, 3676 Hartsfield Rd, Tallahassee, Florida U.S.A.
Ph. (850) 574-3197; Fax (850) 576-3676; chris_reed@urscorp.com

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LONG TERM GOAL

The long-term goal of our research group has been to construct mathematical descriptions of the processes that form sedimentary deposits at all spatial scales on continental margins, from storm beds to the deposits of 100,000 yr sea level cycles, and to conduct numerical experiments leading to the prediction of the sedimentary fabric (structure and stratification pattern) of the resulting deposits.

OBJECTIVES

At small time and space scales (1 cm-50 cm depth into the seabed; 1 hr-3 yr sedimentary record), we have tested the hypothesis that on muddy shelves such as the northern California shelf, Holocene event stratigraphy consists of the deposits of high-concentration storm regimes associated with river floods, alternating with deposits of low-concentration storm regimes, in which river flooding does not occur. At intermediate spatial scales (1 -20 m depth into the seabed; 1-1,000 yrs), we have tested a second hypothesis; that facies assemblages are stacked on, or are capped by, erosional bounding surfaces (source diastems,) and that these patterns are responses to progressive sorting and stratal condensation mechanisms. At large time and space scales (1 -1,000 m depth into the seabed; 100-2.5 million yrs) we have tested the hypothesis that depositional sequences can be explained in terms of shifts in the equilibrium configuration of shelf surface in response to changes in sea level, the rate and character of sediment input, and the hydrodynamic climate.

APPROACH

We have tested the short-term sedimentation (“flood” bed) hypothesis by simulating event beds from time series of bottom velocity and concentration measurements, and by comparing them with observations (box cores, piston cores, and seismic records). Two algorithms have been developed. EVENT I describes the transport of sediment as dilute, near bottom suspensions (low concentration regime). EVENT II describes the transport of sediment as fluid mud flows on the sea floor (high concentration regime; Fan et al., 2001; in press). A second deterministic model for sediment transport

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14. ABSTRACT
The long-term goal of our research group has been to construct mathematical descriptions of the processes that form sedimentary deposits at all spatial scales on continental margins, from storm beds to the deposits of 100,000 yr sea level cycles, and to conduct numerical experiments leading to the prediction of the sedimentary fabric (structure and stratification pattern) of the resulting deposits.

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(SLICE) describes fluid circulation and sediment transport on continental margins in response to waves, wind-driven currents and tides, using the wind field as input.

We have tested the hypothesis for intermediate scale sedimentation (facies assemblage hypothesis) by linking deterministic algorithms for boundary layer sedimentation (EVENT I, Event II) with a probabilistic algorithm for stratal succession. (FACIES; Zhang et al.,1997, 2000; Fan et al., 2001). In order to test the hypothesis for long-term sedimentation (equilibrium margin hypothesis) We have combined the morphodynamical model for continental margin evolution developed by URS Corp (1995) with Mike Steckler's (1993) geodynamical model, leading to a combined stratigraphic model (SEQUENCE)

In the last year of work we have undertaken two efforts. First, the SLICE model has been tested against additional data sets. Secondly, the model was employed to support model parameter definitions for the large-scale SEQUENCE model. Finally, FACIES has been embedded in SEQUENCE so that facies characteristics can be assigned to the spaces between the bounding surfaces in SEQUENCE simulation.

WORK COMPLETED

Working codes now exist for Event I, EVENT II, SLICE, FACIES, and SEQUENCE. Simulations from these models compare favorably with stratigraphic observations from the northern California shelf.

RESULTS

Simulations using EVENT I, EVENT II and SLICE (Fig. 2) show that short lived, coast-hugging, surface flood plumes, forming over the inner shelf of northern California during winter storms, leave behind them slowly consolidating, high-concentration, near-bottom suspensions (fluid mud). If the flood is accompanied by elevated wave heights, or if it is followed by elevated wave heights before the mud consolidates, then offshore transport of the fluid mud occurs, as it respond to its own excess density. Later spring and summer resuspension episodes are less likely to involve significant flood discharge, and wave resuspension of sea floor sediment during these events results in more dilute suspensions (low concentration regime). These more dilutes suspensions do not form fluid muds, but are passively borne seaward and alongshelf by wind driven currents. The resulting storm beds are thin and sand rich, partly as a consequence of *in situ* winnowing, and partly as a consequence of advection of sand from the further inshore (Fan et al., in press). A simulation of the deposits of the last glacial sea level oscillation (the last 125 thousand years) on the eel sector of the northern California shelf depict a complex assemblage of high-frequency sequences, similar to those seen on seismic records.

The hydrodynamic and sediment transport components of the SLICE model have been tested against numerous data sets. The model has successfully reproduced the time-dependent flow and suspended sediment transport measurements in flow tunnel experiments of Ribberink, et al. (1994) In addition, the model has now been successfully applied to profiles and time series data from the field experiments of Wright (1999) The hydrodynamic component has also been verified against surface velocity data collected as part of the Rutger's CODAR program (Glenn, 2000). Fig. 2. shows the comparison of measured (Wright, 1999) and simulated (SLICE) suspended sediment concentrations at 15 cm above

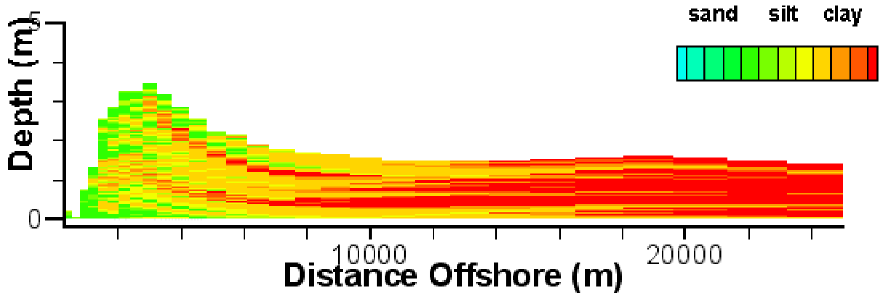

Fig. 1. Simulation by SLICE showing 500 years of sedimentation on the Eel Sector of the Northern California shelf/

the bed. The model comparison is good, and provides confidence in the application of SLICE to cross-shore sediment transport simulations. Fig. 3 shows a comparison of measured and simulated surface velocities. The measured data have been obtained from the Rutger's CODAR program (Glenn, 2000). The measured data correspond to a three-day wind event with the wind blowing to the North. The surface currents are responding to the forcing and flowing parallel to the coast. The SLICE simulation of the same event demonstrates good agreement with the measured velocities over the near and mid-shore regions.

The primary role of SLICE in this year's effort has been to support the development of large-scale model parameters. The basic approach is to use the calibrated process-based SLICE model (general circulation, sediment transport and morphodynamic model) to generate long-term data sets (100s of years) in a depositional environment. Each simulation represents detailed hydrodynamic response to wind (storm) and tide forcing, and the subsequent erosion, transport and deposition of sediment. The time series output from the model simulations is processed to develop long-term time-average depth-integrated sediment fluxes and concentrations along the cross-shore profile. These data are then used to develop associated large-scale advection and diffusion properties of each sediment grain size class. The properties developed in this approach are then used to set large-scale model advection and diffusion coefficients. The SLICE model has been configured to simulate about 500 years of deposition on a shelf similar to the Eel Shelf on the west coast of the U.S. using two grain sizes for comparison. The grain sizes were chosen so that a 'coarser' sediment class would produce net deposition at a nearshore location and a'finer' grain sediment which would produce net deposition near the shelf edge. During the simulation, sediment was periodically supplied to the system at the near shore boundary to simulate a sediment source due to river discharge.

Fig. 4 shows the cross-shore profile, the sediment deposits (at the end of 500 years), the depth integrated time-average fluxes and depth-integrated time average concentrations. The deposits show two distinct depositional areas, one for the coarse material centered at about 3 km offshore, and the second, for the fine grained material centered at about 15 km offshore. Some fine grained material is resident in the coarse grain material deposit, due to trapping and armoring of the fine material as the coarse grain deposit evolved. These results from the long-term time-averaged data set are much different than the anticipated uniform 'effective' advection and may indicate that the cross-shelf transport is better represented by a combination of advection and diffusion. The development of analysis methods to distinguish between advection and diffusion representations, and the determination of optimal representations for each transport mode is the subject of ongoing research. The SLICE model will be used extensively to provide long-term data sets for this research.

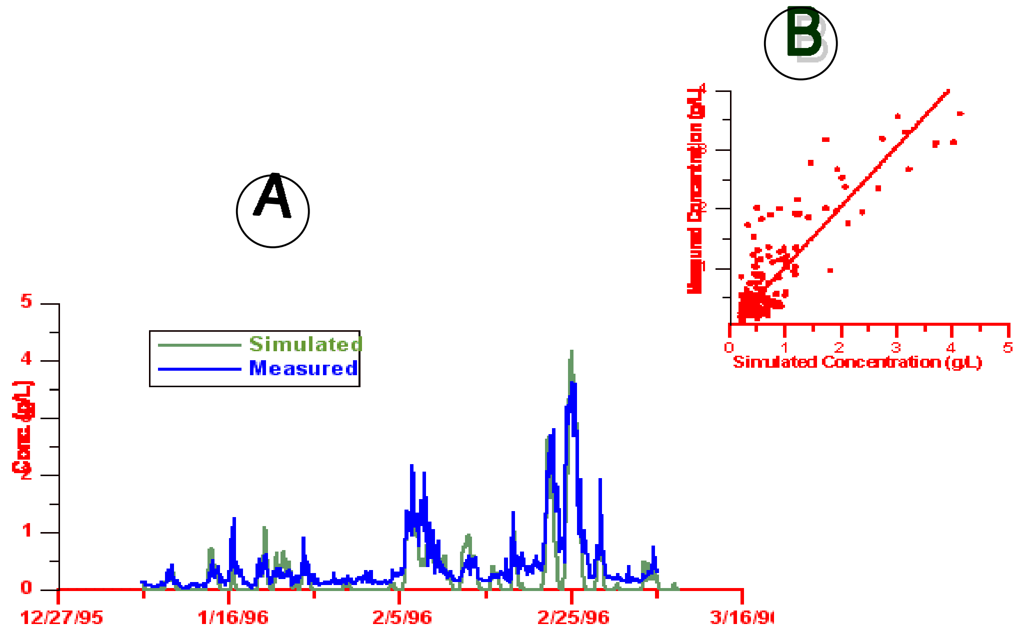

Fig. 2. Calibration to suspended sediment data. A: Comparison of simulated suspended sediment concentrations with measurements from the VIMS tripod at 15 cm above the sea floor. B: Correlation plot or C > 0.2 g/l

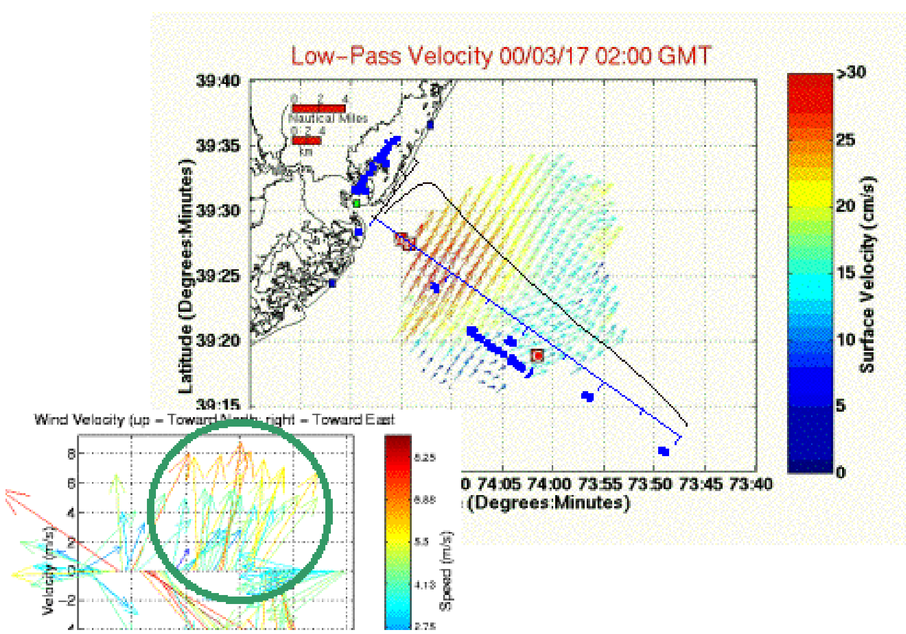

Fig. 3. Calibration to surface velocity data.

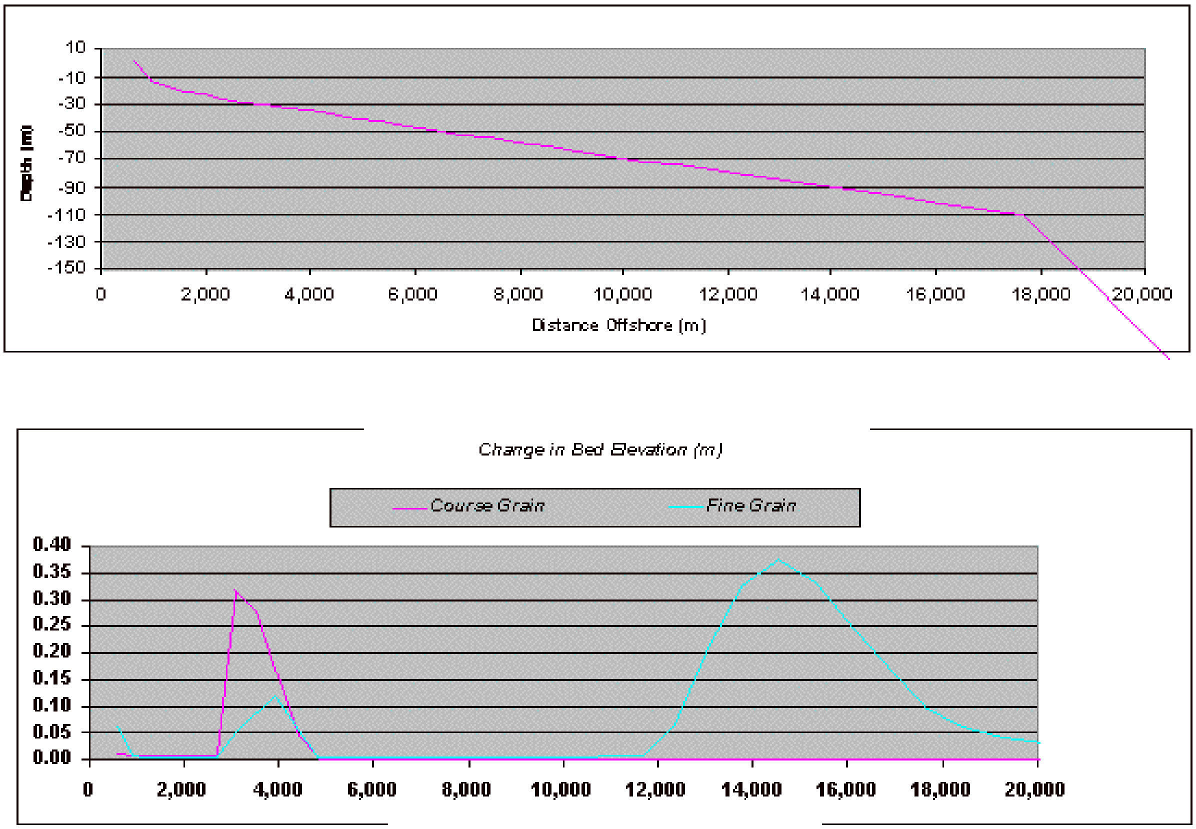

Fig. 4. Results of the calibration. Above: Model shelf profile. Below: Net deposition.

IMPACT/APPLICATIONS

EVENT I and EVENT I are being modified to predict the geotechnical and acoustic properties of first meter of the sea floor. FACIES will then predict the geotechnical and acoustic properties of first 10 meters of the sea floor. SLICE and SEQUENCE will predict seafloor structure at depths up to several kilometers, for foundation studies and petroleum exploration.

TRANSITIONS

We have contribute directly to other STRATAFORM modeling groups. The SLICE model has been configured for combination with SEDFLUX (Syvitski et al., 1997), in order to provide predictions of shelf sedimentation and sediment transport to the slope region Chris Reed and Alan Niedoroda are coordinating with staff from INSTAAR to complete the integration process. Also, the SLICE model is being used to deduce parameters for use in the SEQUENCE model (Steckler, 1999). The larger oceanographic community outside of STRATAFORM are also consumers of our products. We are presently exchanging code with Peter Cowell, University of Sidney, Australia, and other members of the PACE group (Predicting Aggregate Coastal Evolution) funded by the European Economic Community.

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